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COMPARISON OF INJURY INCIDENCE BETWEEN THE T-11 ADVANCED TACTICAL PARACHUTE SYSTEM AND THE T-10D PARACHUTE, FORT BRAGG, NORTH CAROLINA, JUNE 2010-NOVEMBER 2013

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14. ABSTRACT:

This report compares injury rates between the older T-10D parachute and the newer T-11 parachute. From June 2010 to November 2013 (3.5 years) data were systematically collected on jump operations performed by the 82nd Airborne Division, XVIII Airborne Corps, and 18th Air Support Operations Group using these parachutes. Data on injured jumpers were collected on the drop zone and followed up with medical records. Operational data were collected from flight manifests and flash reports and included parachute type, time of day, type of jump (administrative/non-tactical or combat loaded), aircraft, aircraft exit door (right, left, tailgate), jump order (order in which the Soldiers exited the aircraft), Soldier's rank, drop zone, and entanglements. Temperature, humidity, heat index, and wind speed were obtained on the drop zone using a Kestrel® Model 4500 pocket weather tracker. There was a total of 131,747 jumps resulting in 1,101 injured Soldiers for a crude incidence of 8.4 injuries/1,000 jumps. Most injuries (88%) with a known injury mechanism were associated with ground impact. In univariate analysis, risk of injury with the T-10D was 9.1/1,000 jumps, and that with the T-11 was 5.2/1,000 jumps (odds ratio (T-10D/T-11)=1.72, 95% confidence interval (95%CI)=1.45-2.08, p<0.01). Other factors that independently increased injury risk included night jumps, combat loads, higher wind speeds, higher temperatures, certain aircraft, and entanglements. After controlling for these factors in a multivariate analysis, injury risk was still higher for the T-10D parachute when compared to the T-11 (odds ratio (T-10D/T-11)=1.56, 95%CI=1.28-1.89, p<0.01). For virtually all strata of the independent risk factors, the T-11 had a lower injury rate than the T-10. One exception was the few cases of entanglements (n=36). Entanglement incidence was higher with the T-11 (0.51 vs. 0.22 entanglements/1,000 jumps, risk ratio=2.37, 95%CI=1.20-4.69, p<0.01) and when an entanglement occurred, injury risk tended to be higher with the T-11 (0.69 vs. 0.39 injuries/entanglement, risk ratio=1.77, 95%CI=0.95-3.31, p=0.08). Compared to the T-10, the T-11 parachute had a lower injury incidence under virtually all the operational conditions examined here, except in the rare case of an entanglement.

15. SUBJECT TERMS: Flight manifest, flash reports, administrative/non-tactical, Hollywood, combat load, drop zone, entanglements, rank, door position, tailgate, C130 Hercules, C17 Globemaster, C23 Sherpa, C160 Transall, CH47 Chinook, UH60 Blackhawk, C212 CASA, temperature, humidity, wind speed, parachute landing fall, tree landing, static line, safety

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1 SUMMARY

1.1 Introduction and Purpose

Parachuting injuries are the 6th leading cause of hospitalizations in Department of Defense active duty Soldiers. Since 1952, the T-10Dserved as the main United States (US) Army parachute for mass tactical operations. It is rated for a maximal load of 350 lbs (Soldier and equipment). However, since 1952, the average weight of the US Soldier and the equipment carried has increased. During Operation Just Cause in 1989, 4% of airborne Soldiers jumping into Panama carried loads above 350 lbs. In parachute operations in Iraq and Afghanistan (2001-2003) average parachute loads (Soldier and equipment) were 327 to 380 lbs. The need for a new parachute system to accommodate the greater Soldier loads was recognized in 1994 and work between then and 2010 led to the development and implementation of the T-11 Advanced Tactical Parachute System (ATPS). The purpose of this project was to compare injury rates between the legacy T-10D parachute system and the newer T-11 ATPS while controlling for other factors known to influence injury rates during airborne operations.

1.2 Methods

From June 2010 to November 2013 (3.5 years), injury and operational data were systematically collected on jump operations performed by the 82nd Airborne Division, XVIII Airborne Corps, and 18th Air Support Operations Group during jumps at Fort Bragg and Camp McCall, North Carolina. Soldiers used both T-10D and T-11 parachutes. For each jump operation, one or more investigators were present on the drop zone and recorded each injured Soldier's initial injury diagnosis, anatomical location of the injury, and how the injury occurred. The initial diagnosis and anatomical location were provided by a medic or physician's assistant. If the injured Soldier was evacuated to the hospital, a physician obtained a final diagnosis and anatomical location from medical records.

Operational data were collected from routine reports (flight manifests and flash reports) issued by the units. These data included the date and time of the jump, unit involved, drop zone, parachute type, entanglements, Soldiers' rank, jump order (order in which the Soldiers exited the aircraft), aircraft type, aircraft door side (right, left, tailgate), and type of jump. Entanglements were physical contact between two or more jumpers that interfered with a normal descent. Type of jump could be administrative/non-tactical (Hollywood) or combat loaded. Weather data (temperature, humidity, heat index, and wind speed) were obtained by the on-site

investigators using a calibrated Kestrel® Model 4500 pocket weather tracker.

Cumulative injury incidence was calculated as ∑ jumps with one or more injuries divided by ∑ jumps multiplied by 1,000 (injuries/1,000 jumps). Univariate logistic regression assessed the association between injuries and parachute systems, operational data, and weather data. Backward stepping multivariate logistic regression was used to assess the association between injuries and these factors in combination. An odds ratio (OR) and 95% confidence interval (95%CI) were calculated.

1.3 Results

There were a total of 131,747 jumps resulting in 1,101 injuries for a crude injury incidence of 8.4/1,000 jumps. Most injuries (88%) with a known injury mechanism were associated with ground impact. In univariate analysis, risk of injury with the T-10D was 9.1/1,000 jumps and 5.2/1,000 jumps with the T-11 (OR=1.72, 95%CI=1.45-2.08, p<0.01). Other factors that independently increased injury risk included night jumps, combat loads, higher wind speeds, higher temperatures, type of aircraft, and entanglements. After controlling for these factors in a multivariate analysis, injury risk was still higher for the T-10D parachute when compared to the T-11 (OR=1.56, 95%CI=1.28-1.89, p<0.01). For virtually all strata of the independent injury risk factors, the T-11 had a lower injury risk than the T-10D. An exception was in the very few cases of entanglements (n=36 in 131,747 jumps). Entanglement incidence was higher with the T-11 (0.51 vs. 0.22 entanglements/1000 jumps, risk ratio=2.37, 95%CI=1.20-4.69, p<0.01) and when an entanglement occurred, injury risk tended to be higher with the T-11 (0.69 vs. 0.39 injuries/entanglement, risk ratio=1.77, 95%CI=0.95-3.31, p=0.08).

1.4 Conclusions and Recommendations

Compared to the T-10, the T-11 parachute had a lower injury incidence under virtually all the operational conditions examined here, except in the very rare case of an entanglement. The T-11 parachute had a lower injury incidence even after accounting for a number of other major injury risk factors including night jumps, combat loads, higher wind speeds, higher temperatures, and types of aircraft. A major reason to adopt the use of the T-11 ATPS during mass tactical operations is the lower injury rate under virtually all operational conditions examined term.

2 REFERENCES

See Appendix A for a listing of references used within this report.

3 AUTHORITY

Under Army Regulation 40-5,[2] the US Army Center for Health Promotion and Preventive Medicine (now the AIPH) is responsible for providing program evaluations and epidemiological consultation services related to injury prevention and control. This project was approved and funded by the DSOC, the AIPH, and PM PMCIE to determine differences in injury rates between the legacy T-10D parachute and the new T-11 parachute. The project was reviewed by the AIPH Public Health Review Board and approved as a public health practice project.[3]

4 INTRODUCTION

In 2003, the Secretary of Defense directed the Department of Defense to reduce preventable mishaps or injuries. The Under Secretary of Defense for Personnel & Readiness responded by establishing the Defense Safety Oversight Council (DSOC) which chartered nine task forces to develop recommendations to achieve this objective. One of these task forces was the Military Training Task Force (MTTF), which worked to decrease injuries during military training activities. Each year, the MTTF prioritized a number of projects to reduce training-related injuries. In 2010, the MTTF funded a project for the United States (US) Army Institute of Public Health (AIPH) and Concurrent Technologies Corporation (CTC) to compare injury rates between the legacy T-10D parachute and the newer T-11 Advance Tactical Parachute System (ATPS).

On a night jump on 25 June 2011 there was a total malfunction of a T-11 parachute. The jumper with the malfunction did not activate his reserve parachute, resulting in his death. All jumps with the T-11 parachute were suspended while an investigation was undertaken. A Safety Investigation Board charged with looking into the incident determined the failure of the T-11 was "caused by a combination of debris retained within the chute and improper packing. The two mistakes combined to create a situation where the debris, coupled with a partially blocked 'air channel' resulted in a torn canopy that could not properly inflate. The board determined that a number of T-11s packed for use at Bragg had similar issues". The board made a number of recommendations and on 1 August 2011 the Army-wide suspension on T-11 jumps was lifted. The board allowed Fort Bragg to follow their own plan for resumption of T-11 use. Jumps with the main T-11 parachute were not resumed at Fort Bragg until January 2012.

The funds from the contract with the DSOC were exhausted by December 2011 and a preliminary report on the study results was published.[1] At that point, only about 4,000 jumps with the T-11 had been completed. The US Army Institute of Public Health (AIPH), Directorate of Epidemiology and Disease Surveillance, obtained funding for an additional year of data collection. This was to obtain a greater number of jumps to make a more comprehensive comparison of injury rates between parachutes. The data collection was continued from December 2010 to December 2011. Near the conclusion of this period, Program Executive Office (PEO), Project Manager for Clothing and Individual Equipment (PMCIE) requested a preliminary analysis of the data. This analysis suggested that the number of T-11 night jumps was not adequate and PEO PMCIE funded the study for a third year (2013), primarily to increase the number of T-11 night jumps. This was important because combat operations are likely to be conducted at night and knowledge of injury rates at night is therefore critical. To extend the funding, fewer T-10D jumps were observed in 2013 and the emphasis was placed on observing more T-11 jumps.

The major purpose of this report is to compare injury rates between the T-10D and T-11 parachutes while controlling for other known airborne injury risk factors including night jumps, combat loads, and high wind speeds. In addition, several other potential risk factors that have received limited attention were examined (e.g., drop zone, aircraft, military rank, entanglements, jump order).

5 BACKGROUND

5.1 Early History of Military Airborne Operations

Benjamin Franklin may have been the first to propose the use of parachutes for military operations. Inspired by Etienne Montgolfier's hot air balloon flight he wrote in 1784: "Where is the Prince who can afford so to cover his country with troops for its defense, so that ten thousand men descending from the clouds might not, in many places, do an infinite amount of mischief before a force could be brought to repel them?" Napoleon Bonaparte conceived a plan to invade England using balloon troops. However it was not until World War I (WWI) that the technology existed to make this a more realistic possibility. Colonel Billy Mitchell, commander of United States (US) aviation units in France, proposed an airborne parachute assault in October 1918. To break the stalemate that had been introduced by the trench and machine gun, Mitchell proposed to drop parachutist behind German lines near Metz in Northeast France. Heavy bombers would be used that could each carry a squad of troops. The troops would be armed with machine guns, supplied with airdrops, and supported with attack aircraft. WWI ended the next month and the operation was never realized.[4-6]

In April 1928 the US Army's first experimental jump was conducted at Brooks Field near San Antonio. It involved 6 Soldiers jumping from a number of aircraft. The first person out of the aircraft was Master Sergeant Edwin Nichols who worked on Mitchell's staff in France and was instrumental in the development of early airborne technology. The first mass tactical operation was made at Kelly Field near San

Antonio in September 1929. It involved 18 jumpers from 12 aircraft (9 Dehavillands and 3 Douglas biplanes) jumping at 2,000 feet above ground level and using manually activated parachutes. In three to four minutes after landing the Soldiers had assembled three Browning water cooled machine guns for firing. [4, 7, 8]

Representatives from the Soviet Union observed the demonstration at Kelly Field and this may have served as a stimulus for the development of Soviet airborne operations that may have already been underway. In August 1930, the Soviet Army made an inaugural drop of 12 troops and in 1933 dropped a light company of 62 troops. The Soviet Army began dropping brigade sized units by 1935 and in 1936 it was reported that over 5,000 Soviet Soldiers jumped from aircraft in a training operation near Kiev. By 1936 there were 559 jump towers and 115 airborne training sites in the Soviet Union. The first Soviet combat jump was in the Russo-Finnish War in 1939. By 1941, the Soviet Army had 15 parachute brigades.[7, 8]

Kurt Student, who became the Commander of the German Airborne Forces in WWII, observed a Soviet airborne jump of 1,500 troops in 1935 and was impressed with the operation. In January 1936, Hermann Goring, then Chief of the Air Force and Air Transport Minister, issued orders for the raising of a parachute regiment called the *Fallschirmjager-Regiment 1* in Stendal, Northwest Germany. In the same year and at the same location, the Wehrmacht (German Army) formed a parachute company called the *Fallschirm-Infanterie-Bataillon,* which was rapidly increased in size to a full battalion. The first German combat jumps were scheduled for October 1938 as part of the invasion of Czechoslovakia but the Czechs conceded without a fight and the operation was cancelled. Near the end of 1938, Chancellor Adolf Hitler ordered that all airborne forces be transferred to the Luftwaffe (German Air Force) which assumed all airborne operations under General Student. Small airborne units were committed to action in the successful German invasions of Denmark and Norway in April 1940, but the first major German airborne assaults of company and battalion strength spearheaded the successful German invasion into the Netherlands in May 1940. Airborne troops captured key bridges, airfields, and fortifications that were critical for the advance of German ground troops.[9, 10]

There were no further developments in the US after the jumps at Kelly Field in 1929 because shortly after, a directive was issued by the War Department to cease Airborne experimentation. Nonetheless, in May 1939, spurred by the developments in Germany, the Chief of Infantry proposed the development of an “air infantry”. In April 1940, a plan proposed by the Infantry Board was approved by the War Department. An Airborne Test Platoon was formed with 48 men in June 1940 and they were trained at Fort Benning, Georgia. The first mass tactical jumps were conducted in August 1940 from C-47 Skytrain aircraft at Lawson Field on Fort Benning. The 501st Parachute Battalion was activated in September 1940 and training facilities rapidly improved. The US entered WWII in December 1941 with the attack on Pearl Harbor and the subsequent declaration of war by Germany. In January 1942, the War Department directed that four parachute regiments be formed. Airborne Divisions were later formed but consisted of only 8,400 men, as opposed to a normal infantry division that had 15,000. The 82nd Airborne Division executed the first US combat jumps into Sicily in July 1943. Winds of 35 miles/hour caused transport aircraft to go off course and many troops were dropped south of planned drop zones. Only about half of the troops made it to their rally points, but nevertheless, most of the missions assigned to the individual units were accomplished.[4, 8]

5.2 Parachute Systems

Since the introduction of airborne operations, physicians and scientists have worked with the operational community to enhance safety and increase the probability that Airborne Soldiers arrived on the ground ready for their missions. One of the major improvements in airborne operations has been progress in parachute technology. Military parachutes designed for intentional jumps from aircrafts were designed as “T” type parachutes. The “T” initially indicated ‘training’ but by mid-WWII the “T” had become understood to mean a “troop”. “T” parachutes were intended for deliberate, premeditated jumps from aircraft to distinguish them from parachutes used by aviators for emergency escapes. The first parachute actually used by the soldiers of first US Army Airborne Test Platoon in 1940 was designated the “T-4”. The T-4 system was designed as a ripcord parachute but it was modified by the test unit for static line deployment. The T-4 had a 15-foot static line, a pack tray that did not totally encompass the parachute canopy, and was difficult to don and doff. The T-5 was adopted in the summer of 1941 and was designed from the start for static line deployment. The T-5 pack tray was wire reinforced to make it rigid and it was made of heavy cotton duck fabric. The T-5 had a very severe opening shock. The T-7 followed, and by the end of WWII the T-7 had a single point release system that could easily collapse the parachute canopy once the jumper had landed. All early parachutes had 28-foot flat circular canopies (when inflated) with 22-foot (T-4 and T-5) or 24-foot (later T-5 and T-7) diameter reserve parachutes. The T-4, T-5, and T-7 were all canopy first opening systems, although it was generally assumed that a safer system with less opening shock might be devised by having the canopy risers (canopy suspension lines) deploy first. Canopy deployment with all these early parachutes could be erratic depending on winds and the aircraft slip stream.[4, 7, 11]

Beginning in 1952, the Army began replacing the T-7 with the T-10 and by 1954 implementation by the US Army was completed. The T-10 served as the main US Army personnel parachute system up to 2010.[7] With the T-10 the risers came out first, followed by the canopy. This allowed jumpers to fall below the aircraft slip stream before the canopy deployed and this reduced the opening shock. The T-10 system had a 26-foot inflated parabolic canopy, a total weight of 44 lbs, and was rated for a maximum load (jumper and equipment) of 350 lbs. The T-10 was designed and developed when the estimated average load of the soldier and his equipment was about 300 pounds.[12, 13] However, soldier body weights and combat loads have progressively increased since the 1950's.[12, 14-16] One study of 624 Rangers who jumped into Panama during Operation Just Cause (19 December 1989) found that 24 (4%) carried loads that exceeded the maximum allowable.[12] During airborne operations in Afghanistan in 2001 and in Iraq in 2003, *average* loads (Soldiers and equipment) ranged from 327 to 380 pounds.[17]

The need for a new parachute system to accommodate the greater Soldier loads was recognized in 1994 and work between that time and 2010 led to the development and implementation of the T-11 Advanced Tactical Parachute System (ATPS). The T-11's rate of descent is 19 ft/sec (5.8 m/sec), compared to the T-10's rate of 22 ft/sec (6.7 m/sec). Crude estimates of the kinetic energy (KE=1/2 mass X velocity^2) on ground impact for the two parachute systems are in Table 1.

Table 1. Estimates of the Kinetic Energy (KE=1/2 mass X velocity^2) of the T-10D and T-11 Parachutes on Ground Impact

Parachute	Soldier Mass (kg)	Velocity (m/sec)	Kinetic Energy (Joules)
T-10	80	6.7	1796
T-11	80	5.8	1346

Because of its shape (modified cruciform), the oscillations of the T-11 are highly dampened and the parachute becomes vertically stable very soon after deployment.[13, 18] The T-11 reserve parachute has characteristics similar to the main parachute and the aerodynamics are such that if both the main and reserve parachutes are deployed, they do not interfere with each other. However, because of the large canopy, the T-11 likely has more lateral drift, less free air space on mass tactical jumps, and a greater drag hazard once the jumper has landed. The T-10D and T-11 parachutes are shown in Figure 1.

Two previous studies compared the T-11 parachute to the T-10. One[19] involved Soldiers at the US Army Airborne School (USAAS) who performed their first jump with the T-11, although 7% performed their first jump with the T-10D and second with the T-11. In this investigation only daytime, administrative/non-tactical jumps were considered. Injury rates were 44% lower with the T-11 compared to the T-10. The second study[1] was the preliminary one referred to earlier as part of this project. In this investigation, injury rates were 52% lower with the T-11 but the overall number of T-11 jumps (n=4,117), especially night jumps, was very low. This led to the decision to collect additional data to more definitively examine differences between the T-10D and T-11 under a broader spectrum of operational conditions.

5.3 Injury Incidence in Airborne Operations

Besides improvements in parachute technology, there have been continuous improvements in aircraft exit procedures, ground landing techniques and other factors that appear to have substantially reduced the number of injuries over time.[7, 20-23] Table 2 displays investigations that have examined military airborne injuries and provides injury definitions, military units involved, methods of injury data collection, and crude injury incidences for these investigations. Studies are arranged by year and in groups that include airborne basic training, operational units, single jump operations, and combat operations. Early estimates of military parachuting injury rates in the WWII era were 21 to 27/1,000 descents.[24, 25] A summary of studies conducted after this time (up to 1998) indicated that airborne injuries averaged about 6/1,000 jumps.26 Nonetheless, different injury definitions, dissimilar methods of data collection, and diverse operational conditions can result in widely different injury rates, as illustrated in Table 1.27-30 For example, Soldiers of the 82nd Airborne Division at Fort Bragg, North Carolina had an airborne injury rate of 11/1,000 jumps,1 compared to the historical average of 6/1,000 jumps noted above.26 Soldiers in the 82nd Airborne Division conduct many jumps at night with combat loads, factors known to increase injury risk.25, 31-35 The two studies of injuries during combat operations demonstrated some of the highest airborne injury rates recorded.[12, 17]

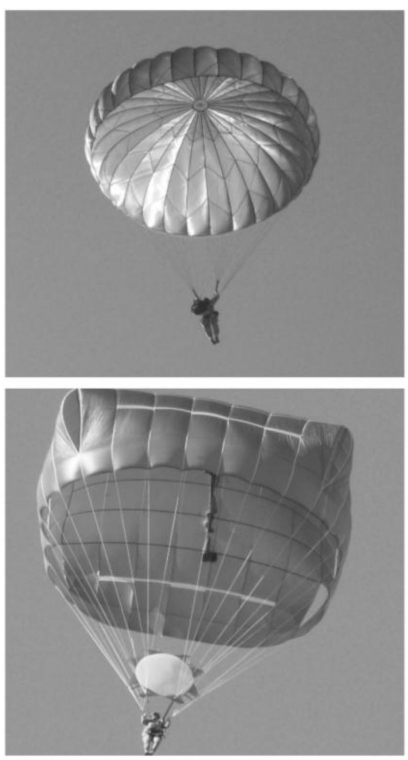

Figure 1. The T-10D (top) and T-11 (bottom) Parachutes

Table 2. Military Static Line Airborne Injury Incidences

Group	Study	Injury Definition	Group, Location, Date (if available in article)	Collection of Injury Data	Jump Conditions (if specified)	Crude Injury Incidence (injuries/jumps = injuries/1,000 jumps)
Airborne Basic Training	Tobin et al. 1941[24]	Injuries recorded by training battalion	501st and 502rd Parachute Battalion, Parachute School, Ft Benning GA, Aug 1940 to Aug 1941	Personnel records		121/4,490= 27.0/1,000[a]
	Pozner 1946[36]	Not clear	3rd Parachute Training Unit, British, Jan 1944 to Jun 1945	Consolidated accident statistics		190/66,408= 2.9/1,000[b]
	Hallel & Naggan 1975[34]	Paratrooper who received medical treatment on drop zone or several days following jump	Mixed basic course and refresher course, Israeli	Punch cards identifying injuries on drop zone		723/83,718= 8.6/1,000[a]
	Pirson & Verbiest 1985[35]	Not clear	Basic jump course; some Soldiers in refresher training, Belgium, 10-year period	Accident reports identifying injuries on the drop zone		5/1,000 [c]
	Lowdon & Wetherill 1989[37]	Fractures, head injuries, dislocations, and others	Training Services Parachute Training Airfield near Oxford, British, 6-year period	Emergency room records, 6 years		205/51,828 = 4.0/1,000
	Pirson & Pirlot 1990[38]	Not clear	Paracommando basic course, Belgium, Feb 1985 to Mar 1988	Not clear		53/15,043= 3.5/1,000
	Bar-Dayan et al. 1998[39]	Casualty that prevented further jumps for at least 2 days	Parachute training, with minority of jumps for refresher course or maneuvers, Israel	Accident reports completed by physicians		388/43,542= 8.9/1,000
	Amoroso et al. 1998[40]	Any musculoskeletal or traumatic condition between aircraft exit & exiting the drop zone resulting in inability to clear the drop zone, or diagnosed in medical clinic or hospital ER	Airborne School, Ft Benning, GA	Drop zone with follow-up at hospital/emergency room and patient medical records		35/3,674= 9.5/1,000
	Knapik et al. 2008[27]	Questionnaire item asking if student injured during jump week	Airborne School, Ft Benning GA, June 2005 to January 2006	Questionnaire responses		119/6,708= 17.7/1,000
	Knapik et al. 2008[33]	Physical damage to the body recorded on updated injury report	Airborne School, Ft Benning GA, April 2005 to December 2006	Drop zone injuries reported by medics with follow up at clinic/hospital		596/102,784= 5.8/1,000

Group	Study	Injury Definition	Group, Location, Date (if available in article)	Collection of Injury Data	Jump Conditions (if specified)	Crude Injury Incidence (injuries/jumps = injuries/1,000 jumps)
Operational Units	Essex-Lopresti 1946[25]	Causalities reported by the medical officer on the drop zone	British 6th Airborne Div, January to November 1944	Drop zone		437/20,777= 21.0/1,000
	Neel 1950[41]	Time loss injuries	82nd Airborne Division, Ft Bragg, NC, 1946-1949	Not clear		1,018/174,220= 5.8/1,000
	Roche 1960[42]	Events causing hospitalization and time loss from duty	101st Airborne Division, 1956 to 1959	Injury statistics from 101st Airborne Division		1,206/355,886= 3.4/1,000
	Hadley & Hibst 1984[22]	Injury resulting in loss of duty for 1 day or more	82nd Airborne Division, Ft Bragg, NC, Fiscal Year 1979 to 1980	Not clear		117/186,717= 0.6/1,000
	Lillywhite 1991[32]	Parachute injury seen by medical personnel on the drop zone	5th Airborne Brigade, British	Medical personnel on drop Zone		379/34,236= 11.1/1,000
	Farrow 1992[23]	Injury requiring evacuation from drop zone, withdrawal from exercise, duty restriction, or hospitalization	Parachute Battalion Group, Australian, Mar 1987 to Dec 1988	Injuries recorded on a standard Field Medical Report		63/8,823= 7.1/1,000
	Kragh et al. 1996[28]	Acute anatomical lesion resulting in a duty restriction as a result of parachuting	3rd Ranger Battalion, Ft Benning GA, USA, 55-month period	Medical records of unit Soldiers		163/7,569= 21.5/1,000
	Craig & Morgan 1997[43]	Injury from time boarding aircraft to ground impact and identified by ER staff as due to parachuting	Fort Bragg NC, USA, May 1993 to December 1994	Emergency room records		1,610/200,571= 8.0/1,000
	Schumacher et al. 2000[44]	Parachute-related injury that limited duty for 1 or more days	3d Ranger Battalion, Ft Benning GA, USA, October 1996 to December 1997	Database containing all sick call and emergency room visits		210/13,782= 15.2/1,000
	Craig & Lee 2000[45]	Injury from time boarding aircraft to ground impact and identified by ER staff as due to parachuting	XVIII Airborne Corps, Ft Bragg NC, USA, May 1994 to April 1996	Emergency room records		1,972/242,949= 8.1/1,000
	Hay 2006[46]	Injury requiring evacuation from drop zone, admission to medical facility, withdrawal from exercise, or duty restriction	3rd Battalion, Royal Australian Regiment & A Field Battery, Jan to Dec 2004	Audit of unit medical records	Daylight jumps only	21/1,375= 15.3/1,000
	Hughes & Weinrauch 2008[47]	Injuries recorded in unit medical records	4th Battalion Royal Australian Regiment, Feb 2004 to Feb 2005	Audit of medical records		28/554= 50.5/1,000

Group	Study	Injury Definition	Group, Location, Date (if available in article)	Collection of Injury Data	Jump Conditions (if specified)	Crude Injury Incidence (injuries/jumps = injuries/1,000 jumps)
	Knapik et al. 2011[31]	Any physical damage to the body seen by the medical personnel on the drop zone.	82nd Airborne Division, Ft Bragg NC, Jun-Dec 2010	Direct recording on drop zone followed up with medical records, where available		242/23,031= 10.5/1,000
	Knapik et al. 2011 [1]	Any physical damage to the body seen by the medical personnel on the drop zone.	82nd Airborne Division, Ft Bragg NC, Jun 2010 to Nov 2011	Direct recording on drop zone followed up with medical records, where available		678/63,487= 10.7/1,000
Single Jump Operation	Timboe 1988[29]	Injuries treated by medical personnel on the drop zone	Elements of 82nd Airborne parachuting into Ft Irwin, March 1982	Drop zone injuries	Early morning jump, combat loads, rough landing zone, high winds	158/1,780= 88.8/1,000
	Kragh & Taylor 1996[28]	Concussions, fractures, contusions, sprains, strains, lacerations	1/75th Ranger Battalion, jump onto Ali Al Salem Airfield, Kuwait, Dec 1991	Drop zone injuries recorded by medical personnel	Night jump, combat loads, high winds (10-13 knots), airfield and rocky desert drop zone	71/475= 149.5/1,000
	Craig et al. 1999[30]	Injury from time Soldier boarded aircraft until exiting the drop zone	US and British units jumping at Ft Bragg NC, May 1996	Drop zone injuries recorded by medical personnel, or at emergency room	Low visibility, ground fog, winds did not exceed 8 knots, temp=55^{0}F	US 67/3,066= 21.9/1,000 British 49/1,688= 29.0/1,000
	Buxton et al.2006[48]	Not clear	British and French parachute operation	Not clear		41/740= 55.4/1,000
Combat Operations	Miser et al. 1995[12]	Any injury reported by the Ranger during an interview	2nd Battalion, 75th Ranger Regiment, jump onto Panama Airfield (Operation Just Cause), Dec 1989	Interview	Night jump, combat load, airfield drop zone	252/486= 518.5/1,000
	Kotwal et al. 2004[17]	Physical damage to the body as a result of parachuting, from aircraft exit to release of parachute harness on ground	75th Ranger Regiment; 4 combat jumps: 2 in Iraq (Operation Iraqi Freedom) & 2 in Afghanistan (Operation Enduring Freedom), 2001 to 2003	Ranger electronic medical database	Winds 1-8 knots, night jumps, combat loads, 40-60^{0}F	76/634= 119.9/1,000

[a]Injury incidence cited by authors is incorrect
[b]Includes deaths
[c]This is the incidence cited in the article but the article does not provide numerators or denominators
Abbreviations: Ft=Fort, Jan=January, Feb=February, Mar=March, Jun=June, Dec=December, GA=Georgia, NC=North Carolina, CA=California, Div=Division, ER=emergency room, USA=United States of America, F=Fahrenheit.

5.4 Airborne Injury Risk Factors

Studies on other factors that influence airborne injury rates are shown in Table 3. Early studies identified higher wind speeds, night jumps, heavy loads, and rough landing zones as factors that increased injury risk. [25, 34] Later studies identified such extrinsic risk factors as smaller diameter canopies, fixed wing aircraft (verses rotary wing), and extra equipment (combat loads). Intrinsic risk factors included female gender, older age, greater body weight, lower upper-body muscular endurance, lower aerobic fitness, and prior injuries.[1, 27, 31, 32, 35, 38, 45, 49, 50] Many studies only carried out univariate analysis of these risk factors while a few[1, 27, 31-33] performed multivariate analysis that allowed identification of independent risk factors and their interactions.

Table 3. Military Static Line Parachute Injury Risk Factors

Investigation	Injury Case Definition; Soldiers or Military Unit; Year of Data Collection	Jumps	Risk Factor	Strata[a]	RR[b]	95% Confidence Interval
Essex-Lopresti, 1946[25]	Any injury recorded on drop zone; British Airborne Division; 1944	20,777	Wind speed Time of day Aircraft Body weight	16–20/0–5 mph Night/Day (0–10 mph winds) Plane/Balloon (0–15 mph winds) >70/<70kg	3.3 1.2 1.6 [cd]	2.0–5.5 0.9–1.8 0.8–3.4 [c]
Hallel and Naggan, 1975[34]	Any injury recorded on drop zone and hospitalizations several days after jump; Israeli paratroopers; no dates provided	83,718[e]	Time of day Drop zone Training	Night/Day Rough/Sand Refresher Course/Basic Course	2.4 3.2 2.0	2.1–2.9 2.5–4.1 1.3–3.1
Hadley and Hibst, 1984[22]	Injuries before canopy deployment with ≥one day of limited duty; US airborne division; 1979–1980	186,717	Aircraft exit	No staggered exit/staggered exit	13.2[f]	0.8-234.0[f]
Pirson and Verbiest, 1985[35]	Severe and moderate injuries(contusions, abrasions excluded) from accident reports; male Belge airborne trainees, soldiers in refresher courses, and soldiers on maneuvers; 1974–1983	201,977	Parachute Wind speed Time of day Aircraft Equipment Temperature Humidity	22/28 m^2 canopy (balloon) 22/28 m^2 canopy (airplane) 18/0–7 mph Night/Day (balloon) Plane/Balloon (day, no equipment) Yes/No (airplane, day jumps) >24/<24°C 100/40%	8.3 3.7 5.0 4.1 3.1 1.6 1.7[g] 1.0[g]	7.6–9.0 3.4–8.9 [c] 3.7–4.6 2.8–3.4 1.5–1.8 [c] [c]
Pirson and Pirlot, 1990[38]	No injury definition; Belge airborne trainees; 1985–1988	14,356 to 15,043	Body weight Body height	82 to 87/58 to 63 kg 1.86–1.90/1.62–1.67 m	2.0 1.3	0.6–6.7 0.2–7.8
Lillywhite, 1991[32]	Any physical damage to the body recorded on drop zone; British Airborne Brigade; prior to 1989	34,236	Aircraft Time of day Equipment Wind speed Wind bearing Number exiting Wedge[h]	Plane/Helicopter Plane/Balloon Helicopter/Balloon Night/Day (plane) Night/Day (helicopter) Yes/No (plane) Yes/No (helicopter) 14–15/0–2 mph Rear/Other Directions 65–90/1–22 Yes/No	7.3 11.2 1.6 1.3 41.2 10.4 26.9 4.7[g] 1.4 2.5 [cd]	2.7–23.5 5.9–24.2 0.5–5.1 0.9–1.9 3.8–449.5 2.6–41.6 2.8–257.4 [c] 1.2–1.8 1.9–3.3 [c]

Investigation	Injury Case Definition; Soldiers or Military Unit; Year of Data Collection	Jumps	Risk Factor	Strata[a]	RR[b]	95% Confidence Interval
Farrow 1992[23]	Physical damage to the body requiring evacuation from drop zone, withdrawal from exercise, duty restriction, or hospitalization; Australian Parachute Training School; 1987-1988	8,886	Equipment Exits	Yes/No Simultaneous/Not Simultaneous	4.1 2.1	2.3-7.3 1.2-3.5
Kragh et al.,1996[28]	Physical damage with duty restriction; US Army Airborne Ranger; no dates provided	7,948	Time of day Drop zone	Night/Day (field and landing strip) Landing Strip/Field (day) Landing Strip/Field (night)	1.9 2.4 2.7	1.4–2.7 1.1–5.2 1.8–4.0
Amoroso et al., 1997[50]	Lower extremity injury requiring restricted duty US Army Safety Center data; 1985–1994	NA[ei]	Gender	Women/Men	2.0[k]	1.4–3.0[k]
Craig et al., 1997[43]	ER visits resulting from airborne activities; XVIII Airborne Corps, Ft Bragg, NC; 1993–1994	200,571	Age	<18–29/≥29 years	2.2	1.9-2.5
Amoroso et al., 1998[40]	Ankle inversion sprains; US airborne trainees; no dates provided	3,674	Ankle brace	No/Yes	6.9	0.9-56.1
Schumacher et al., 2000[44]	Any ankle injury with duty limitation; US Army Airborne Rangers;1994–1997	13,782	Ankle brace	No/Yes	2.9	1.4-6.1
Craig and Lee, 2000[45]	ER visits resulting from airborne activity; XVIII Airborne Corps, Ft Bragg, NC; 1994–1996	242,949	Gender Age	Women/Men >39/17–29 years	1.4 1.4	1.1–1.7 1.2–1.5
Hay 2006[46]	Injury requiring evacuation from drop zone, admission to medical facility, withdrawal from exercise, or duty restriction: 3rd Battalion, Royal Australian Regiment & A Field Battery, Jan-Dec 2004	1,375	Equipment	15 kg/None 40 kg/None	1.1 2.9	0.3-3.7 1.0-2.7
Knapik et al. 2008[33]	Physical damage to the body reported by medics with follow up at clinic/hospital; Airborne School, Ft Benning GA, Apr 2005 to Dec 2006	102,784	Ankle brace Wind speed Time of day Equipment	No/Yes 10-13/0-1 knots Night/Day Yes/No	1.2 1.9 2.3 1.7	1.0-1.4 1.4-2.6 1.8-2.8 1.4-2.0
Hughes & Weinrauch 2008[47]	Injuries recorded in unit medical records; 4th Battalion Royal Australian Regiment; Feb 2004 to Feb 2005	554	Landing zone Body weight	Land/Water ≥100/≤70 kg	4.3 2.5	1.8-10.1 0.6-10.5

Investigation	Injury Case Definition; Soldiers or Military Unit; Year of Data Collection	Jumps	Risk Factor	Strata[a]	RR[b]	95% Confidence Interval
Knapik et al. 2008[27]	Questionnaire item asking if student injured during jump week; Airborne School, Ft Benning GA; Jun 2005 to Jan 2006	6,708	Time in service	>4 years/≤1 year	4.1	3.1-5.3
			Dominate hand	Left/Right	1.3	0.6-2.6
			Smoking	Yes/No	1.1	0.7-1.8
			Age	≥30/17-19 yrs	3.3	1.7-6.7
			Height	186-211/152-173 cm	2.0	1.1-3.7
			Weight	84-129/48-72 kg	2.8	1.4-5.6
			Body mass index	25.9-40.8/17.4-23.0 kg/m^2	1.7	0.9-3.2
			Push-ups	10-55/78-120 repetitions in 2 min	2.1	1.0-4.5
			Sit-ups	40-65/83-120 repetitions in 2 min	1.3	0.7-2.5
			2-Mile run	14.1-21.0/9.5-12.7 min	2.9	1.4-6.1
			Airborne recycle	Yes/No	2.1	1.2-3.7
			Ankle brace	No/Yes	1.7	1.1-2.7
			Exit problems	Yes/No	2.8	1.3-6.2
			Prior injury	Yes/No	3.5	2.2-5.4
Knapik et al. 2011[31]	Physical damage to the body reported by medics on the drop zone with follow up at clinic/hospital; 82nd Airborne Division, Ft Benning GA; Jun to Dec 2010	23,031	Time of day	Night/Day	2.6	2.0-3.4
			Equipment	Yes/No	3.2	2.5-4.2
			Wind speed	11-12/0-1 knots	2.2	1.1-4.5
			Temperature	91-104/37-50 deg F	5.4	1.7-17.4
			Aircraft	Fixed Wing/Rotary Wing	11.3	1.6-81.0
			Humidity	81-92/20-40%	1.7	1.1-2.8
			Exit door	Side/Tailgate	12.3	8.0-18.8
			Jump order	46-51/1-5	1.4	0.4-5.8
			Military rank	Enlisted/Officer	1.1	0.9-1.2
			Entanglements	Yes/No	65.6	43.1-99.8
Knapik et al. 2011[19]	Physical damage to the body recorded on operational reports; Airborne School, Ft Benning GA, Apr 2005 to Dec 2006	30,755	Parachute	T-10/T-11 (daytime, no equipment)	1.8	1.0-3.1
Knapik et al. 2011[1]	Physical damage to the body reported by medics on the drop zone with follow up at clinic/hospital; 82nd Airborne Division, Ft Benning GA; Jun 2010 to Nov 2010	63,487	Parachute	T-10/T-11	2.1	1.4-3.1
			Time of day	Night/Day	1.7	1.5-2.0
			Equipment	Yes/No	2.1	1.8-2.5
			Wind speed	11-17/0-1 knots	2.1	1.4-3.1
			Temperature	91-104/24-50 deg F	1.3	0.9-1.7
			Humidity	81-97/17-40%	1.1	0.8-1.5
			Exit door	Side/Tailgate	4.3	2.4-7.7
			Jump order	46-52/1-5	1.0	0.5-1.8
			Military rank	Junior Enlisted/Junior Officer	1.4	1.0-1.8
			Entanglements	Yes/No	34.5	19.6-58.8

[a] Numerator is factor with higher risk; variables in parenthesis are conditions under which risk factor was calculated.
[b] RR=risk ratio.
[c] Cannot calculate from data given in article.
[d] Risk appears to be elevated based on data presented in article.
[e] Free fall jumps made up less than 5% of total descents.
[f] There were 7 injuries from 95,823 jumps before and 0 injuries from 90,894 jumps after the staggered exit. Risk ratios and 95% confidence intervals calculated by substituting 0.5 for zero cell.[51]
[g] Estimated from graph in article.
[h] The wedge is additional equipment on independent parachutes released just before the jumpers.
[i] NA=not applicable. Cohort study comparing men and women without jump denominators.
[j] Non-simultaneous doors include rear ramps, single side aircraft jumps, and balloon descents.
[k] Not risk ratios but rather the odds ratio and 95% confidence interval for odds ratio.
Abbreviations: US=United States, Ft=Fort, NC=North Carolina, GA=Georgia, Jan=January, Feb=February, Apr=April, Jun=June, Dec=December

6 METHODS

This investigation encompassed the period from June 2010 to November 2013 (3.5 years). From June 2010 through December 2011 data was only collected on the 82nd Airborne Division of the XVIII Airborne Corps. Its mission is to, within 18 hours of notification, strategically deploy, conduct parachute assaults, and secure key objectives for follow-on military operations in support of US national interests. Beginning in January 2012 and continuing through the end of the study in November 2013 data were also collected on elements of the XVIII Airborne Corps and the 18th Air Support Operations Group. The XVIII Airborne Corps maintains a strategic response capability to deploy forces on short notice anywhere in the world by land, air, or sea, to conduct full-spectrum operations as an Army, joint, or combined headquarters. The 18th Air Support Operations Group is an Air Force unit that provides tactical command and control of air power assets for U.S. Army XVIII Airborne Corps. All of these units regularly conduct jump operations to keep Service Members trained for airborne forcible entry missions. All units are garrisoned at Fort Bragg or the adjacent Pope Air Force Base in North Carolina.

6.1 Jump Operations

For all Airborne training jumps, Soldiers donned either T-10D or T-11 parachutes and prepared to board fixed-wing or rotary-wing aircraft. As they entered the aircraft, their names, ranks, and location in the jump order were recorded on a jump manifest. After the Soldiers had completely boarded and were seated, the aircraft departed for the drop zone. Along with the jumpers, the aircraft had a team normally consisting of a primary jumpmaster (PJ), assistant jumpmaster (AJ), and a minimum of two safeties. The PJ and AJ were usually the last two jumpers to exit the aircraft, while the safeties remained onboard and returned with the aircraft to the departure airfield. These four individuals had responsibility for the safety of all on-board jump personnel. During flight, Soldiers were seated until the jumpmaster issued the command to stand up. At this point, the jumpers stood up and attached the static lines of their parachutes to a cable in the aircraft and awaited further commands from the jumpmasters for their exit door. Once the Air Force turned over control of the paratroop door to the jumpmasters, the jumpmasters verified specific geographic landmarks and ground markings to ensure the aircraft was on the proper approach into the drop zone. Once this was confirmed, the jumpmaster then instructed the first jumper to stand in the door. Once the aircraft reached its Aerial Release Point, the jumpmaster issued the command “GO.” On this command, the jumpers exited the aircraft in quick succession. As each jumper exited, the static line pulled open the main parachute, providing the canopy that slowed the jumper’s descent. On contact with the ground, the jumpers executed a parachute landing fall (PLF) to break the impact of the landing.[26, 46] After landing, and while lying on the ground, the jumper collapsed the parachute canopy using a quick release device on the parachute harness. The jumper then stood up, bundled the parachute, and prepared for the follow-on operation.

6.2 Injury Data

During all airborne operations, the drop zone safety officer (DZSO) was the individual on the ground with responsibility for all actions and the safety of all personnel on the drop zone. The DZSO was located at the Personnel Point of Impact of the drop zone, the location where the first jumper should land. Depending on the number of Soldiers involved in the airborne operation, there were from 1 to 6 ambulances located on the drop zone near the DZSO. Each ambulance had 2 to 4 Army-trained medics, and for larger operations a physician's assistant (PA) was present. Once all Soldiers who had jumped were on the ground, the ambulances drove across the drop zone and provided medical care to injured jumpers. They returned injured jumpers to a collection point near the DZSO.

For each jump operation, one or more investigators were present on the drop zone. Once an injured Soldier was brought to the collection point, the investigators recorded the Soldier's name, initial injury diagnosis, anatomical location of the injury, and how the injury occurred. The medic or PA provided the initial diagnosis. If the injury was minor, the Soldier could be released on the drop zone by the medic or PA, but usually Soldiers were taken to a hospital or clinic for follow-up care. Once in the hospital, the medical care provider who saw the Soldier generated a record in the Armed Forces Health Longitudinal Technology Application (AHLTA) that included a more detailed diagnosis and anatomical location. For all Soldiers evacuated to the hospital, a physician examined the AHLTA record and provided a final diagnosis and the anatomical location of the injury. For the purposes of this investigation, if the Soldier was released on the drop zone, the final diagnosis and anatomical location were those obtained on the drop zone. If the Soldier was taken to the hospital the final diagnosis and anatomical location were those determined by the physician from the AHLTA record. During operations with larger numbers of Soldiers, an additional medic was stationed at the hospital to record injuries and to assure that all data were captured. An injury was defined as any physical damage to the body, seen by the medic or PA on the drop zone, from the time the Soldier was seated in the aircraft until the time the Soldier completed the parachute landing and removed the parachute harness on the ground.

6.3 Operational Data

Planned jump operations were published in a document called the "air letter". The air letter contained the projected date and time of the jump, unit involved, drop zone, projected number of jumpers, aircraft, and other information. This allowed the investigators to be on-site for each of the jumps. After the jump operation was completed, a “flash report” was issued that contained information on the actual time of the jump, parachute type (T-10D or T-11), unit, aircraft, entanglements, and some data on injured jumpers. From the time of day and visual operations of the drop zone, investigators could determine if the jump had occurred in daylight (day) or in the dark (night). Entanglements involved physical contact between two or more jumpers that interfered with a normal parachute descent. Information on entanglements was obtained from observations of jumpers made by the investigators, conversations with personnel on the drop zone (primarily the DZSO and malfunctions riggers), and interviews of the jumpers. Flash reports were used to obtain additional information on entanglements. Injury data on the flash report was used to augment injury information obtained on the drop zone and to ensure all injuries were captured.

As Soldiers loaded onto the aircraft, a jump manifest was created. The jump manifest contained information on the Soldiers’ rank, name, jump order (order in which the Soldiers exited the aircraft), door side (right, left, tailgate), aircraft type, and the type of jump. Type of jump could be administrative/non-tactical (Hollywood) or combat load. For an administrative/non-tactical jump operation, Soldiers were dressed in Army combat uniforms, advanced combat helmets, and T-10D or T-11 parachutes with appropriate attached reserve parachutes. For combat loaded jumps, the Soldiers additionally wore weapons containers (for rifles), and rucksacks. The rucksacks and weapons containers were attached to the jumpers’ harnesses by quick release straps and a lowering line. The lowering line served to drop the rucksack and container about 15 feet below the Soldier’s body while remaining attached to the Soldier. The quick release was activated about 100 feet before ground contact.

Most jumps were conducted on drop zones at Fort Bragg (Sicily, Normandy, Holland, Nijmegen, Salerno, Saint Mere Eglise, Gela, and Contentin) or nearby Camp Mackall (Luzon). Three jump operations were conducted at other locations. These included Charleston, West Virginia (Clute drop zone); Little Rock Air Force Base, Arkansas (Rock Air Force Base drop zone); and the Joint Readiness Training Center (JRTC), Fort Polk, Louisiana (Geronimo drop zone). No flash report was filed for the operation at the JRTC and thus little operational data were available.

6.4 Weather Data

Weather data were obtained by the on-site investigators using a calibrated Kestrel® Model 4500 pocket weather tracker (Kestrel® is a registered trademark of Nielsen-Kellerman Company). As each aircraft came over the drop zone, investigators recorded the ground dry bulb temperature, humidity, heat index, and wind speed. The lowest and highest wind speeds were obtained from 3 minutes prior to the aircraft passing over the drop zone until the time that all jumpers had landed. The heat index was calculated using temperature and humidity according to the equation of Steadman.[52]

6.5 Data Analysis

A de-identified database was created that had one jump on each line along with the respective operational data, weather data, and injury information. Data analysis was performed using the Statistical Package for the Social Sciences (SPSS), Version 19.0.0.

Descriptive statistics (n and %) were determined for each type of injury (diagnosis), their anatomical locations, and events associated with the injuries. Cumulative injury incidence was calculated as ∑ jumps with injuries/∑ all jumps X 1,000 (injuries/1,000 jumps). The chi-square statistic was used to examine differences between parachutes for each type (diagnosis) of injury. A risk ratio (RR) and 95% confidence interval (95%CI) were calculated for each comparison.

Univariate logistic regression was used to assess the association between injuries and the operational and weather data. Covariates (risk factors) that were significantly ($p<0.10$) associated with injury incidence in the univariate analysis were included in a backward stepping multivariate logistic regression. In both univariate and multivariate analyses, an odds ratio (OR) and 95% confidence interval (95% CI) were calculated by comparing the injury risk at a baseline level (stratum) of the variable (indicated with an OR=1.00) to the risk at other strata of the variable. The dependent variable in the logistic regressions was the presence or absence of an injury.

Reasons for entanglements were stratified on parachute type and injury (yes/no). Differences in entanglement incidence (∑ entanglements/∑ jumps X 1,000) between the T-10D and T-11 parachutes were compared using the chi-square statistic. Risk of injury if an entanglement occurred was also compared between parachutes using chi-squares. For both comparisons a RR and 95%CI were calculated.

Injury risk was calculated by parachute type on all strata of variables retained in the multivariate model. RRs, 95%CIs, and chi-square statistics were calculated. Because of a relatively small number of jumps in some cells, the Mantel-Haenszel procedure was also used. The Mantel-Haenszel procedure combined ORs for the two parachutes. If there was a common OR the procedure calculated it; if there was no common OR because of an interaction, the procedure produced a weighted average of the separate ORs.[53]

7 RESULTS

During this investigation, the Soldiers made a total of 131,747 jumps resulting in 1,101 injuries for a crude injury incidence of 8.4/1,000 jumps. AHLTA records were available on 95% (n=1,042) of the injuries, with 5% (n=59) having no AHLTA records and diagnosed only by medics or PAs on the drop zone.

Table 4 shows the types of injuries and their anatomical locations. Forty-five percent of injuries (n=493) involved the lower body/lower back, 53% (n=584) involved the upper body, and 2% (n=24) involved multiple sites. The most common injury/anatomical location combinations were closed head injuries/concussions (n=374), ankle sprains (n=81), ankle fractures (n=66), low back strains (n=47), knee sprains (n=36), low back pain (n=32), low back fracture (n=31), hip contusions (n=30), shoulder dislocations (n=20), shoulder strains (n=19), head contusions (n=16), pelvic fractures (n=13), knee contusions (n=12), upper arm contusions (n=12), upper arm strains (n=11), lower back sprains (n=10), and ankle pain (n=10). These combinations (n=820) accounted for 74% of all injuries.

Table 4. Injuries by Type and Anatomical Location

Injuries and Locations	N	Proportion (%)
Injury Type		
Closed Head Injury/Concussion	376	34.2
Sprain	155	14.1
Fracture	148	13.4
Contusion	134	12.1
Strain	108	9.8
Pain (Not Otherwise Specified)	104	9.4
Abrasion/Laceration	37	3.4
Dislocation	24	2.2
Muscle/Tendon Rupture	8	0.7
Other Traumatic	5	0.5
Impingement	2	0.2
Anatomical Location		
Head	403	36.6
Ankle	160	14.5
Lower Back	132	12.0
Knee	63	5.7
Shoulder	53	4.8
Upper Arm	51	4.6
Hip	44	4.0
Pelvis	35	3.2
Foot/Toe	25	2.3
Multiple	24	2.2
Thigh	22	2.0
Neck	18	1.6
Calf/Shin	12	1.1
Lower Arm	11	1.0
Face	9	0.8
Chest	9	0.8
Elbow	8	0.7
Hand/Fingers	8	0.7
Upper Back	6	0.5
Ear	4	0.4
Abdomen	2	0.2
Eye	1	0.1
Wrist	1	0.1

Table 5 shows the types of injuries by parachute. Compared with the T-10, injury risk was lower for the T-11 parachute for all types of injuries except strains and “other” traumatic injuries.

Table 5. Comparison of Injury Types by Parachute

Type of Injury	T-10		T-11		Risk Ratio (95%CI)	Chi Square p-value
	N	Injury Incidence (cases/1,000 jumps)	N	Injury Incidence (cases/1,000 jumps)		
Closed Head Injury/Concussion	338	3.18	38	1.50	2.12 (1.52-2.96)	<0.01
Sprain	134	1.26	21	0.83	1.52 (0.96-2.41)	0.07
Fracture	135	1.27	13	0.51	2.47 (1.40-4.37)	<0.01
Contusion	116	1.09	18	0.71	1.54 (0.93-2.52)	0.09
Strain	84	0.79	24	0.95	0.83 (0.52-1.31)	0.43
Pain (not otherwise specified)	94	0.88	10	0.39	2.24 (1.17-4.30)	0.01
Abrasion/Laceration	32	0.30	5	0.20	1.52 (0.59-3.91)	0.38
Dislocation	21	0.20	3	0.12	1.67 (0.50-5.59)	0.40
Muscle/Tendon Rupture	8	0.08	0	0.00	4.05 (0.23-70.14)[a]	0.30
Other Traumatic	4	0.04	1	0.04	0.95 (0.11-8.52)	0.97
Impingement	2	0.02	0	0.00	1.19 (0.06-24.8)[a]	0.91

[a]0.5 was added to each 2X2 cell to obtain an approximate risk ratio and 95%CI[51]
Abbreviation: 95%CI= 95% confidence interval

Table 6 shows the events associated with the injuries experienced by the Soldiers. In 81% of the injury cases (n=896), it was possible to determine the associated event. Early in the investigation, these data were not systematically collected, accounting for many of the missing events. When events could not be determined later in the project, it was because the Soldier was not sure how the injury had happened or because the investigators could not interview the Soldier before the Soldier was evacuated to the hospital. Most injuries were associated with ground impact and inability to execute a proper PLF. These included landing on uneven ground, on harder surfaces, because of drop zone obstructions (i.e., logs, rocks), or because of improper PLF procedures. Ground impact injuries, static line injuries, entanglements, tree landings, and problems with aircraft exits accounted for 98% (881 of 896) of the known events associated with injury.

Table 6. Events Associated with Injuries

Events	**T-10D (n)**	**T-11 (n)**	**Total (n)**	**Proportion of All Categories (%)**	**Proportion (%) of Known Events (unknowns removed)**
Ground Impact (PLF Problems)	681	108	789	71.7	88.1
Static Line	47	8	55	5.0	6.1
Entanglement	9	9	18	1.6	2.0
Tree Landing	10	1	11	1.0	1.2
Aircraft Exits	8	0	8	0.7	0.9
Dragged by Parachute on Ground	6	0	6	0.5	0.7
Parachute Risers	2	1	3	0.3	0.3
Landed on Equipment	3	0	3	0.3	0.3
Lowering Line	1	0	1	0.1	0.1
Parachute Malfunction (fatal)	0	1	1	0.1	0.1
Towed Jumper	0	1	1	0.1	0.1
Unknown	201	4	205	18.6	---

Abbreviation: PLF=parachute landing fall

Table 7 shows the univariate associations between injury risk and the covariates. Complete data were not obtained on all jumps and the number of jumps for each stratum of each variable is included in Table 7. Higher injury risk was associated with the T-10D parachute, night jumps, combat loads, higher wind speeds, high dry bulb temperatures, humidity, higher heat index, C-130 Hercules and C-17 Globemaster aircrafts, fixed wing aircraft, exits through doors (compared to tailgates), enlisted rank, the Geronimo drop zone (compared to Sicily), and entanglements. Lower injury risk was associated with the Luzon drop zone when compared to Sicily.

Table 7. Univariate Associations between Risk Factors and Airborne Injury Incidence

Variable	Strata	Jumps (n)	Injury Incidence (cases/1,000 jumps)	Odds Ratio (95%CI)	Wald Statistic p-value
Parachute Type	T-10	106,402	9.1	1.00	Referent
	T-11	25,345	5.2	0.58 (0.48-0.69)	<0.01
Time of Day	Day	87,619	6.7	1.00	Referent
	Night	44,128	11.7	1.76 (1.56-1.98)	<0.01
Jump Type	Administrative/Non-Tactical	73,503	5.3	1.00	Referent
	Combat Load	58,243	12.2	2.29 (2.02-2.59)	<0.01
Lowest Wind Speed	0-1 knot	70,036	8.2	1.00	Referent
	2-5 knots	51,801	7.2	0.88 (0.77-1.00)	0.05
	6-11 knots	7,791	12.6	1.55 (1.25-1.92)	<0.01
Highest Wind Speed	0-1 knot	7,009	9.1	1.00	Referent
	2-4 knots	50,135	5.9	0.64 (0.49-0.84)	<0.01
	5-7 knots	45,443	7.9	0.87 (0.67-1.14)	0.30
	8-10 knots	22,103	10.7	1.17 (0.89-1.55)	0.27
	≥11 knots	4,938	17.0	1.88 (1.35-2.61)	<0.01
Dry Bulb Temperature	≤50 degrees F	19,682	7.2	1.00	Referent
	51-70 degrees F	39,478	7.7	1.08 (0.88-1.32)	0.46
	71-90 degrees F	56,161	8.4	1.17 (0.97-1.41)	0.10
	≥91 degrees F	10,334	9.0	1.26 (0.97-1.64)	0.09
Humidity	≤40%	26,893	8.7	1.00	Referent
	41-60%	43,988	8.3	0.96 (0.81-1.13)	0.58
	61-80%	40,446	7.2	0.83 (0.70-0.98)	0.03
	≥81%	14,208	8.4	0.98 (0.78-1.21)	0.82
Heat Index	≤50 degrees F	21,381	7.2	1.00	Referent
	51-70 degrees F	37,669	7.5	1.03 (0.85-1.26)	0.74
	71-90 degrees F	45,490	8.1	1.11 (0.92-1.34)	0.29
	≥91 degrees F	18,778	9.0	1.24 (0.99-1.54)	0.06
Aircraft	C130 Hercules (fixed wing)	83,498	9.0	1.00	Referent
	C17 Globemaster (fixed wing)	33,045	9.5	1.06 (0.93-1.22)	0.35
	C23 Sherpa (fixed wing)	9,051	2.7	0.29 (0.20-0.44)	<0.01
	C160 Transall (fixed wing)	2,160	4.2	0.46 (0.24-0.89)	0.02
	C212 CASA Aviocar (fixed wing)	73	0.0	-----	-----
	CH47 Chinook (rotary wing)	2,667	1.9	0.21 (0.09-0.50)	<0.01
	UH60 Blackhawk (rotary wing)	1,253	0.0	-----	-----
Aircraft Type	Fixed Wing	3,920	8.6	1.00	Referent
	Rotary Wing	127,827	1.3	0.15 (0.06-0.36)	<0.01
Aircraft Exit Door	Left	58,782	8.7	1.00	Referent
	Right	58,797	9.0	1.03 (0.91-1.16)	0.64
	Tailgate	11,791	2.5	0.28 (0.19-0.41)	<0.01

Variable	Strata	Jumps (n)	Injury Incidence (cases/1,000 jumps)	Odds Ratio (95%CI)	Wald Statistic p-value
Jump Order	1-5	23,458	8.5	1.00	Referent
	6-10	22,219	8.6	1.01 (0.83-1.24)	0.89
	11-15	21,240	8.2	0.97 (0.79-1.19)	0.78
	16-20	18,677	8.1	0.95 (0.77-1.17)	0.62
	21-25	17,599	8.8	1.03 (0.84-1.28)	0.76
	26-30	14,062	8.5	1.00 (0.80-1.26)	0.99
	31-35	5,984	7.2	0.84 (0.61-1.17)	0.31
	36-40	3,592	7.8	0.91 (0.61-1.36)	0.66
	41-45	2,873	7.3	0.86 (0.55-1.35)	0.50
	≥46	1,688	8.3	0.97 (0.56-1.68)	0.92
Military Rank	Junior Enlisted (E1-E4)	68,285	9.1	1.00	Referent
	Senior Enlisted (E5-E9)	43,250	8.5	0.94 (0.83-1.07)	0.37
	Warrant Officer (WO1-WO4)	1,371	10.2	1.13 (0.66-1.92)	0.65
	Junior Officer (O1-O3)	15,381	6.2	0.68 (0.55-0.85)	<0.01
	Field Grade Officer (O4-O8)	243	4.1	0.45 (0.06-3.23)	0.43
Drop Zone	Sicily	63,853	8.7	1.00	Referent
	Luzon	23,722	5.9	0.68 (0.56-0.82)	<0.01
	Normandy	16,393	9.3	1.08 (0.90-1.29)	0.41
	Holland	15,965	7.9	0.91 (0.75-1.11)	0.35
	Nijmegen	5,887	7.6	0.88 (0.65-1.20)	0.42
	Salerno	2,304	6.5	0.75 (0.45-1.26)	0.27
	Geronimo	1,654	35.1	4.16 (3.16-5.48)	<0.01
	Saint Mere Eglise	723	2.8	0.32 (0.08-1.28)	0.11
	Rock Air Force Base	700	8.6	0.99 (0.44-2.22)	0.98
	Gela	351	2.8	0.33 (0.05-2.33)	0.27
	Clute	115	0.0	-----	-----
	Contentin	80	25.0	2.94 (0.72-11.97)	0.13
Entanglement	No	131,713	8.2	1.00	Referent
	Yes	36	500.00	107.02 (54.43-210.41)	<0.01

Abbreviations: F=Fahrenheit, 95%CI=95% confidence interval

Table 8 shows the results of the backward stepping multivariate logistic regression. There were 122,525 jumps (93%) that had complete data and could be included in the analysis (logistic regression required complete data on all variables). Independent risk factors for injuries included the T-10D parachute, night jumps, combat loads, higher wind speeds, higher dry bulb temperatures, enlisted rank, the C-130 Hercules and C-17 Globemaster aircrafts, and entanglements.

Table 8. Multivariate Associations between Risk Factors and Airborne Injury Risk

Variable	Strata	Jumps (n)	Odds Ratio (95%CI)	Wald Statistic p-value
Parachute	T-10D	97,914	1.00	Referent
	T-11	24,611	0.64 (0.53-0.78)	<0.01
Time of Day	Day	80,873	1.00	Referent
	Night	41,652	1.30 (1.10-1.53)	<0.01
Jump Type	Admin/Non-Tactical	67,484	1.00	Referent
	Combat Load	55,041	1.84 (1.57-2.15)	<0.01
Highest Wind Speed	0-1 knot	6,630	1.00	Referent
	2-4 knots	47,225	0.96 (0.71-1.29)	0.77
	5-7 knots	43,571	1.37 (1.02-1.84)	0.04
	8-10 knots	21,267	2.20 (1.61-3.01)	<0.01
	≥11 knots	3,832	3.16 (2.16-4.63)	<0.01
Dry Bulb Temperature	≤50 degrees F	19,329	1.00	Referent
	51-70 degrees F	38,384	1.19 (0.97-1.46)	0.10
	71-90 degrees F	54,783	1.22 (1.01-1.49)	0.04
	≥91 degrees F	10,029	1.50 (1.13-1.98)	<0.01
Military Rank	Junior Enlisted (E1-E4)	65,035	1.00	Referent
	Senior Enlisted (E5-E9)	41,181	0.95 (0.83-1.09)	0.50
	Warrant Officer (WO1-WO4)	1,318	1.26 (0.73-2.20)	0.41
	Junior Officer (O1-O3)	14,756	0.67 (0.53-0.84)	<0.01
	Field Grade Officer (O4-O8)	235	0.73 (0.10-5.26)	0.76
Aircraft	C130 Hercules (fixed wing)	77,589	1.00	Referent
	C17 Globemaster (fixed wing)	31,730	1.03 (0.89-1.19)	0.70
	C23 Sherpa (fixed wing)	8,184	0.50 (0.33-0.76)	<0.01
	C160 Transall (fixed wing)	1,609	0.70 (0.35-1.40)	0.31
	C212 CASA Aviocar (fixed wing)	73	-----	-----
	CH47 Chinook (rotary wing)	2,470	0.38 (0.16-0.92)	0.03
	UH60 Blackhawk (rotary wing)	870	-----	-----
Entanglement	No	122,489	1.00	Referent
	Yes	36	153.77 (77.28-305.97)	<0.01

Abbreviations: Admin=administrative, F=Fahrenheit, 95%CI=95% confidence interval

There were 36 entanglements in the 131,747 jumps, resulting in an overall entanglement incidence of 0.27/1,000 jumps. Twenty-nine were entanglements to the ground, four freed before ground contact, and in three cases this was not known. There were 18 injuries associated with these 36 entanglements (50%), with 14 of the injuries involving entanglements to the ground, one of the freed before ground contact, and three not known. Table 9 shows the events associated with the entanglements. Exit problems primarily involved simultaneous exits from both doors of an aircraft (exits are normally staggered), or door delays, both of which resulted in entanglements just after aircraft exits. Entanglements during descent primarily involved jumpers drifting into each other after the parachutes had deployed and where the jumpers did not slip away from each other. The overall risk of entanglement was higher with the T-11 than with the T-10D (0.51 vs. 0.22

entanglements/1,000 jumps, RR=2.37, 95%CI=1.20-4.69, p<0.01). When an entanglement occurred, the injury risk tended to be higher with the T-11 than with the T-10D (0.69 vs. 0.39 injuries/entanglement, RR=1.77, 95%CI=0.95-3.31, p=0.08). T-10D entanglement injuries included fractures (n=3), closed head injuries (n=3), a contusion (n=1), a sprain (n=1) and a strain (n=1). T-11 entanglement injuries included closed head injuries (n=4), strains (n=2), a fracture (n=1), a sprain (n=1), and a case of pain not otherwise specified (n=1).

Table 9. Events Associated with Entanglements

	T-10D		T-11	
	Injured (n)	Not Injured (n)	Injured (n)	Not Injured (n)
Exit Problems	3	7	0	0
Entanglement in Descent	1	7	1	2
Corner Vent Entanglement	0	0	7	2
Unknown	5	0	1	0
Total	9	14	9	4

Table 10 shows injury incidence with parachute type stratified on the independent risk factors in the multivariate analysis. For three aircraft (C160, C212, UH60), no T-11 jumps were conducted and thus no analysis was performed. With few exceptions, the T-11 parachute had a lower injury risk than the T-10D at each strata of each variable. The exceptions were the 0-1 knot high wind speed, warrant officers, field grade officers, and entanglements.

Table 10. Injury Risk with Parachute Type Stratified on Other Independent Injury Risk Factors

Variable	Strata	T-10		T-11		Risk Ratio T-10/T-11 (95%CI)	Chi-Square p-value	M-H Odds Ratio-T10/T11 (95%CI)	M-H p-value
		Jumps (n)	Injury Incidence (cases/ 1,000 jumps)	Jumps (n)	Injury Incidence (cases/ 1,000 jumps)				
Time of Day	Day	67,936	7.2	19,683	4.9	1.48 (1.19-1.84)	<0.01	1.61 (1.34-1.93)	<0.01
	Night	38,466	12.5	5,662	6.5	1.91 (1.37-2.66)	<0.01		
Type of Jump	Admin/Non-Tact	57,053	5.7	16,450	4.2	1.35 (1.05-1.76)	0.02	1.59 (1.32-1.91)	<0.01
	Combat Load	49,349	13.0	8,894	7.2	1.81 (1.40-2.34)	<0.01		
High Wind Speed	0-1 knot	6,154	8.8	855	11.7	0.75 (0.38-1.47)	0.40	1.67 (1.39-2.00)	<0.01
	2-4 knots	41,278	6.1	8,857	5.0	1.22 (0.89-1.69)	0.21		
	5-7 knots	35,624	9.3	9,819	3.0	3.16 (2.16-4.61)	<0.01		
	8-10 knots	16,871	11.6	5,232	7.8	1.48 (1.06-2.06)	0.02		
	≥11 knots	4,356	17.2	582	15.5	1.11 (0.56-2.21)	0.77		
Dry Bulb Temp	≤50 deg F	16,272	7.7	3,410	4.4	1.76 (1.03-3.00)	0.04	1.67 (1.39-2.01)	<0.01
	51-70 deg F	31,918	8.5	7,560	4.6	1.83 (1.29-2.60)	<0.01		
	71-90 deg F	42,896	9.2	13,265	5.7	1.63 (1.27-2.08)	<0.01		
	≥91 deg F	9,332	9.1	1,002	8.0	1.14 (0.55-2.35)	0.72		
Military Rank[a]	Junior Enlisted	55,809	9.7	12,476	5.9	1.64 (1.29-2.09)	<0.01	1.72 (1.43-2.06)	<0.01
	Senior Enlisted	34,928	9.3	8,322	5.3	1.76 (1.29-2.41)	<0.01		
	Warrant Officer	1,015	9.9	356	11.2	0.88 (0.28-2.78)	0.82		
	Junior Officer	11,967	7.1	3,414	2.9	2.43 (1.26-4.66)	<0.01		
	FG Officer	91	0.0	152	6.6	0.56 (0.02-13.61)[b]	0.44		
Aircraft	C130 Hercules	66,557	9.9	16,941	5.1	1.93 (1.54-2.42)	<0.01	1.75 (1.44-2.10)	<0.01
	C17 Globemaster	27,386	10.0	5,659	7.2	1.38 (1.00-1.92)	0.05		
	C23 Sherpa	6,940	2.9	2,111	1.9	1.52 (0.52-4.44)	0.44		
	C160 Transall	2,159	4.2	0	-----	-----	-----		
	C212 Aviocar	73	0.0	0	-----	-----	-----		
	CH47 Chinook	2,033	2.0	634	1.6	1.25 (0.14-11.14)	0.84		
	UH60 Blackhawk	1,253	0.0	0	-----	-----	-----		
Entangle-ment	No	106,379	9.0	25,332	4.9	1.84 (1.53-2.22)	<0.01	1.79 (1.49-2.16)	<0.01
	Yes	23	391.3	13	692.31	0.57 (0.30-1.06)	0.08		

Abbreviations: Admin/Non-Tact=Administrative/Non-Tactical, Deg F=Degrees Fahrenheit, Temp=Temperature, 95%CI=95% Confidence Interval, M-H=Mantel-Haenszel; FG=Field Grade

[a]Junior Enlisted=E1 to E4, Senior Enlisted=E5-E9, Warrant Officer=WO1-WO4, Junior Office=O1-O3, FG Officer=O4-O9

[b]0.5 was added to each 2X2 cell to obtain an approximate risk ratio and 95%CI[51]

Figure 2 shows the crude injury incidences plotted by quarters (3 month periods) for both parachutes. For the T-10, the injury rate was higher in late 2010 and early 2011 than at any other time. T-10D injury rates then decreased in later 2011, leveling off around the beginning of 2012. There were no T-11 jumps from June 2011 (month of the fatality) through December 2011. There were only 99 T-11 jumps in October through December 2010 and 149 T-11 jumps in January through March 2012. Visual examination of Figure 2 indicates that T-11 injury rates were lower than T-10D rates in each quarter, except in April through June 2012 where there were only 500 T-11 jumps.

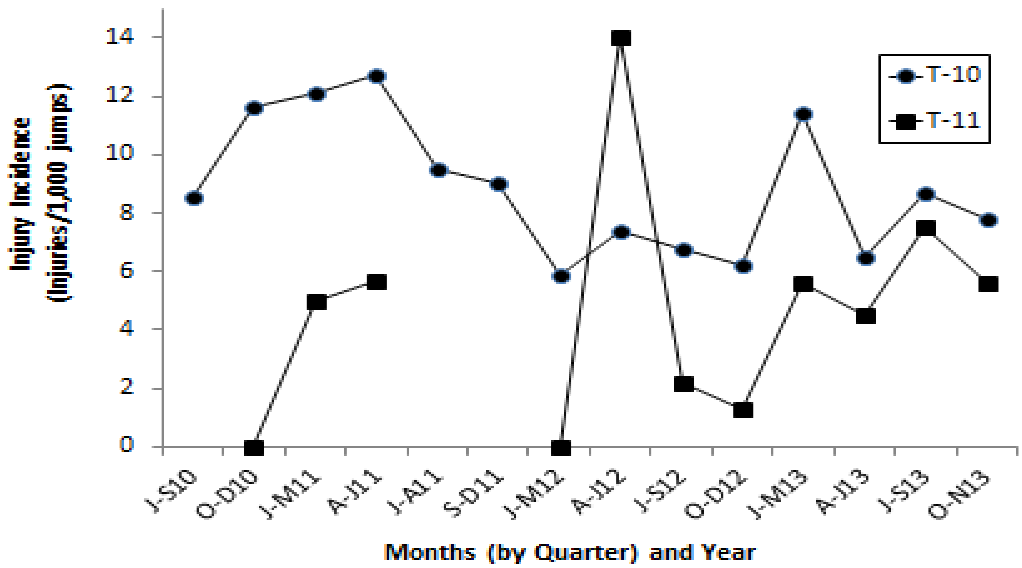

Figure 2. Injury Incidence by Parachute and Quarter (3-month periods).
(Abbreviations: J-S=July through September; O-D=October through December; J-M=January through March; A-J=April through June; O-N=October through November)

Table 11 shows the injury data separated into three time periods (see Figure 2). Periods where no T-11 jumps were conducted were not considered (July through September 2010 and July through December 2011). At all three periods with both T-10D and T-11 jumps seen in Table 11, the T-10 had a higher injury risk than the T-11, although the difference was considerably reduced in 2013.

Table 11. Injury Incidence By Parachute for Three Time Periods During Investigation

Time Period	T-10		T-11		Risk Ratio – T10/T11 (95%CI)	Chi-Square p-value
	Jumps (n)	Injury Incidence (cases/ 1,000 jumps)	Jumps (n)	Injury Incidence (cases/ 1,000 jumps)		
October 2010-July 2011	32,224	12.1	4,117	5.3	2.28 (1.48-3.48)	<0.01
January 2012-December 2012	36,873	6.6	4,764	2.9	2.23 (1.30-3.82)	<0.01
January 2013-November 2013	8,675	7.8	16,464	5.8	1.33 (0.98-1.82)	0.07

8 DISCUSSION

8.1 Comparison of Parachutes

The present investigation found that the overall cumulative injury incidence was 43% lower with the T-11 (univariate analysis) compared to the T-10D parachute over the 3.5 years of the study. The T-11 had a lower injury risk even after the multivariate adjustment for other major and significant injury risk factors including time of day, type of jump, wind speed, temperature, aircraft, and entanglements. Stratifying injury risk on parachute type showed that with few exceptions, injury risk was lower in almost all strata of these independent risk factors. Compared to the T-10, the T-11 had a lower injury risk during day and night jumps, during administrative/nontactical and combat loaded jumps, during jumps at all temperatures, during jumps on all types of aircraft, at most wind speeds (except 0-1 knots), and for most military ranks (except warrant officers and senior officers). Where there were exceptions, the differences were generally small and of low statistical significance.

The only unfavorable finding with regard to the T-11 was the higher entanglement incidence and the trend toward a higher injury incidence if an entanglement occurred. The absolute risk of a T-11 entanglement injury was very small (1 in 2,816 jumps) with only 9 occurring in 25,345 jumps. The most common T-11 entanglement was that involving a corner vent (69% of all T-11 entanglements). In this type of entanglement, one jumper fell through one of the four corner vents of another jumper's T-11 parachute (see Figure 1). We observed this to occur when jumpers passed too close to one another while their T-11 main parachutes were still going through the deployment process. As the lower jumper's parachute elongated and the canopy was partially inflated, the higher jumper's body passed through one of the corner vents. Once the lower jumper's canopy fully inflated, the higher jumper was left suspended from the lower jumper's corner vent. Of the 9 entanglements of this type, 7 (78%) resulted in an injury. Because of our position on the drop zone (near the DZSO), we could observe some corner vent entanglements in the air but could not observe the ground landings. Simulations of T-11 corner vent entanglement were conducted at Yuma Proving Ground, Arizona using mannequins.[54] In 16 drops, mannequins generally landed 10-12 feet apart with average impact velocities of 5-6 m/sec. The 10-12 foot difference would likely allow adequate distance between jumpers to execute a proper PLF. The *average* impact velocities were somewhat lower than a single, untangled T-11 parachute. However, examination of the graphs in the report[54] showed that there were a range of impact velocities, up to a maximum of about 10 m/sec. Thus, impact velocities could be high in some circumstances. In addition, it was possible that the entanglement could interfere with establishing the body position necessary to execute a proper PLF. The present investigation suggested a high possibility of injury when corner vent entanglements occurred under normal training procedures.

When the injury data were examined over time, it was found that yearly injury risk difference between parachutes was about the same in 2010 and 2011. That is, the T-10D risk was about twice as high as the T-11 risk. However, in 2013, the risk difference was considerably reduced such that the injury risk with the T-10D was only about 1.3 times higher than the T-11. This was due primarily to a higher injury risk with the T-11 in 2013 (compared to 2012) since the injury risk with the T-10D was about the same in 2012 and 2013. In 2013, there was a deliberate attempt to observe more T-11 jumps and fewer T-10D jumps because of the large number of T-10D jumps obtained in previous years. Thus, the T-10D jump coverage was not as comprehensive as in past years. The smaller risk difference in 2013 suggests that it would be prudent to continue surveillance on T-10D and T-11 injury rates in future years to obtain a more comprehensive picture of T-11 injury rates.

It is possible to speculate that the reduced injury incidence with the T-11 may have been associated with the slower descent velocity and reduced oscillations when compared to the T-10D. The lower descent velocity would reduce the ground impact velocity, the event associated with the largest number of injuries. In partial support of this concept, T-10D ground impact injuries were 6.4/1,000 jumps, while that of the T-11 was 4.3/1,000 jumps (RR=1.50, 95%CI=1.22-1.83, $p<0.01$). Besides reducing the descent velocity, oscillations are virtually absent with the T-11 once the parachute is fully open[13, 18]. Parachute oscillations can increase the horizontal velocity and when added to the vertical descent velocity can also increase ground impact forces. Oscillations can also complicate the execution of a proper PLF since the jumper may impact the ground at an angle rather than from an upright (vertical) position.

We conducted two previous investigations with the T-11 parachute. In one investigation,[19] basic airborne trainees at the US Army Airborne School performed their very first jump (for 7% it was their second jump) with the T-11. All subsequent jumps were conducted with the T-10D. Because the T-11 jump was a daytime, administrative/non-tactical jump, the T-10D was compared to the T-11 under these conditions only. The overall injury risk was 44% lower with the T-11. In the present investigation, injury risk during daytime, administrative/non-tactical jump was 26% lower with the T-11 (5.7 vs. 4.2 injuries/1,000 jumps, RR=1.35, 95%CI=1.03-1.77, $p=0.03$), a smaller risk reduction than that found at the Airborne School. The other previous investigation[1] involved a portion of the database used in this report, including data collected up to November 2011. In this prior study, there was a 23% difference in injury between parachutes for injuries under these conditions (daytime, administrative/nontactical jumps), very similar to the difference found over the entire 3.5 years of the study.

Importantly, most operational airborne missions will be conducted at night with combat loads. When considering only night jumps with combat loads, injury incidences with the T-10D and T-11 were 13.6/1,000 jumps and 7.3/1,000 jumps, respectively (RR=1.86, 95%CI=1.29-2.67, p<0.01), indicating that higher risks can be expected during night jumps using the T-10D.

8.2 Overall Injury Incidence

The overall crude injury incidence of 8.4 injuries/1,000 jumps in the present study was lower than the 10.7 and 10.5 injuries/1,000 jumps we found in previous analyses involving a portion of the same database and the same cohort of Soldiers.[1, 31] This is likely accounted for by the larger number of T-11 jumps with their lower injury rate, as well as the reduction in T-10D injury rates beginning in 2011 (see Figure 2). The overall crude injury rate with the T-10D was 9.1 injuries/1,000, lower than the incidence of 11.1/1,000 jumps reported in a study of a British operational unit[32] where the investigator defined and collected injuries in a manner almost identical to that of the present investigation. Another British study that collected data in a similar manner during WWII had a much higher injury incidence of 21.0/1,000 jumps,[25] but these data were obtained at a time when military airborne techniques and equipment were in an early stage of development. In studies where more restrictive injury definitions were used (e.g., time loss injuries, hospital visits), incidences of 0.6 to 51/1,000 jumps have been reported. When all injuries and jumps were combined in the studies with restrictive injury definitions (6,408 injuries in 1,192,446 jumps) the incidence was 5.4/1,000 jumps.[22, 23, 28, 41-46] Injury incidences in basic airborne training (post-1950) have ranged from 4 to 10/1,000 jumps. When all jumps and injuries were combined in these basic training studies (2,000 injuries in 300,589 jumps) the incidence was 6.7/1,000 jumps.[33-35, 37-40] Variations in injury incidences may be attributed not only to differences in injury definitions and training experience, but also to the risk factors that likely differ in the different investigations.

Other than our two previous investigations that used portions of the database reported here[1, 31], there have been three reports involving Soldiers and drop zones at Ft Bragg, North Carolina.[30, 43, 45] One study[30] reported an injury incidence of 24.6/1,000 jumps for a single jump operation with troops jumping with T-10 parachutes at night with combat loads. In the present study, if only T-10D night jumps with combat loads were considered, the overall injury incidence was 13.6/1,000 jumps, considerably lower than that of Craig et al.[30] Two other studies[43, 45] surveyed T-10 parachute injuries seen in the emergency room at the Fort Bragg Womack Army Community Hospital from May 1993 to December 1994 and from May 1994 to April 1996. The crude injury incidences were 8.0 and 8.1 /1,000 jumps in the two periods, respectively. In the present investigation, when only injuries with AHLTA records and jumps involving T-10D parachutes onto Ft Bragg drop zones were considered, the injury incidence was 8.3/1,000 jumps, very similar to that of the other two previous investigations.[43, 45]

8.3 Events Associated with Injury

Other than our previous studies that used a portion of the data base reported here,[1, 31] only three studies have actually reported events associated with military parachuting injuries,[23, 41, 45] although others have provided speculation and anecdotal observations on how injuries might occur.[25, 55-57] When events were reported in the three previous studies,[23, 41, 45] the categories differed from those in the present investigation. Nonetheless, these previous studies provide at least some basis for comparison. Neel[41] reported on 140 parachute injury cases at Fort Bragg in 1946. At least 61% of injuries were associated with ground impacts and 6% were associated with aircraft exits. Farrow[23] provided details on 63 injuries experienced by the Australian Parachute Battalion Group from March 1987 to December 1988. The battalion jumped from C130 Hercules and C7 Caribou (tailgate exit) aircraft using T-10 parachutes. Ground impacts, exit procedures, and tree landings accounted for 59%, 10%, and 6%, respectively, of activities associated with injury. This compares with 88%, 6% (including static line injuries), and 1%, respectively, in the present investigation.

By far, the event associated with the largest number of injuries was ground impact. To reduce the number of ground impact injuries, PLFs were introduced into the American Army in 1943. Weekly injury reports issued at the Fort Benning, Georgia Parachute School in 1943 suggested that injuries were trending downward before the PLF became Airborne doctrine, but injuries were definitely reduced just after introduction of the PLF.[7, 20, 21] PLFs as executed today require that, prior to ground contact, the Soldier keep feet and knees together, with hips and knees slightly flexed. The Soldier makes ground contact with the balls of the feet, then rapidly distributes the kinetic energy of the impact through the body by falling sideways and allowing the feet, calves, thighs, buttocks, and back to sequentially make contact with the ground.[26, 46] This series of contacts can be made difficult or impossible if the ground is uneven or has obstructions. Under these conditions, soldiers may not be able to keep their legs and knees together or make the required rapid series of ground contacts across the body. Wind conditions can exacerbate problems by causing greater parachute oscillations that result in greater impact energy (at least with the T-10). Winds from the front of the Soldier can force a jumper into a rear PLF which is very difficult to properly execute.

Craig and Lee[45] reported on T-10 altitude injuries at Fort Bragg from May 1994 to April 1996 (24 months). Altitude injuries were defined as those occurring from aircraft exit to just before ground impact. They reported that 6% of all parachute injuries were of this type and that the incidence was 0.46/1,000 jumps. In the present investigation, if T-10D injuries associated with static lines, exit procedures, entanglements, and parachute riser injuries were combined, they would account for 7% of all injuries (66 of 968 T-10D injuries) and an incidence of 0.62/1,000 jumps (66 in 106,402 jumps). The incidence in the present study is 1.34 times higher than that of Craig and Lee.[45] There were 18 T-11 injuries associated with static lines, exit procedures, entanglements, and parachute riser injuries accounting for 14% of all T-11 injuries (18 of 133 injuries) and an incidence of 0.71/1,000 jumps (18 in 25,345 jumps). The difference in the overall altitude injury incidence between parachutes was small (RR(T-10/T-11)=0.87, 95%CI=0.52-1.47, p=0.61).

Static line problems accounted for the second largest number of injuries in the present investigation. Fort Bragg requires that all static line problems be listed on flash reports. The incidence of T-10 static line injury in Craig and Lee's study[45] was 0.15/1,000 (37 in 242,949 jumps) while that in the present investigation was almost 3 times as great, 0.44/1,000 jumps (47 in 106,402 jumps). There were 8 static line injuries with the T-11 resulting in an incidence of 0.32/1,000 jumps (8 in 25,345 jumps) (RR(T10/T11)=1.41, 95%CI=0.66-2.94, p=0.38). Injuries of this type occur when the static line is not properly handed to the safety, if the safety does not properly clear the static line, or if the parachutist's arm is wrapped around the line on aircraft exit. Proper training in static line management and attention to detail when handing off the static line to the safety can reduce injuries of this type. Jumpmaster training should emphasize key elements in static line management so jumpmasters can recognize and rapidly correct situations where static line injuries might occur.

8.4 Injury Risk Factors

In the present investigation, support was provided for the classic military airborne risk factors. That is, higher injury incidence was associated with higher wind speeds,[1, 25, 31-33, 35] night jumps,[1, 25, 28, 31-35] and combat loads.[1, 31-33, 35] We also replicated results from our previous investigations[1, 31] of risk factors for Airborne injuries (discussed below), as would be expected since some of the same data was used.

8.4.1 Entanglements

The T-10D entanglement incidence of 0.22/1,000 jumps in the present study was substantially lower than the incidence of 0.87/1,000 jumps reported in Airborne School training at Fort Benning, Georgia.[33] The lower incidence may reflect the higher level of experience among the 82nd Airborne Division Soldiers. The primary cause of high altitude entanglements is assumed to be weak and simultaneous exits from opposite sides of the aircraft such that the aircraft slip stream forces jumpers towards each other as their parachutes deploy. Hadley and Hibst[22] studied a procedure called the controlled alternating parachute exit system (CAPES) in which jumpers exited the 2 sides of the aircraft at slightly different times (e.g., a 1-sec delay). This resulted in a substantial decrease in high altitude entanglements from 0.71/1,000 jumps in the year before the procedure was employed to 0.19/1,000 jumps in the year that the procedure was first instituted. In practice, jumpers have a difficult time maintaining the 1-sec separation. If a Soldier rushes the door or hesitates slightly, this can disrupt the timing and still result in simultaneous exits from both sides of the aircraft.

When an entanglement occurred, there was a high probability of an injury. Eighteen of the 36 entangled jumpers were injured (50%) with 14 remaining entangled to the ground, one freed before ground contact, and 3 unknown. It should be remembered that the number of entanglements was small. Nonetheless, the large proportion of injuries associated with the entanglements supports the training practice of instructing Soldiers to disentangle as soon as possible.

As noted above, the T-11 had a larger entanglement incidence than the T-10. Our previous investigation[19] at the Airborne School at Ft Benning suggested just the opposite, that entanglement incidence was lower with the T-11. However, this latter finding may have been an artifact: in that investigation, the T-11 was used primarily on the first training jump and more time than usual was allowed between jumpers for aircraft exits. This may have reduced the risk of entanglements. The larger canopy of the T-11 would reduce free airspace between jumpers during descents and might elevate entanglement risk. With the T-10, if one jumper finds himself/herself on the top of the parachute it is possible to “run off” the top because of the conical shape and the firm surface of the inflated canopy. This may be more difficult with the T-11 because its shape is not as curved. Escape from a corner vent entanglement is very difficult, if not impossible.

8.4.2 Wind Speed

A number of previous studies have shown that a higher injury incidence was associated with higher wind speeds,[1, 25, 31-33, 35] and higher wind speed was an independent injury risk factor in the present investigation. Winds increase the horizontal velocity vector of the jumper and increase ground impact velocity when added to the vertical velocity vector. High winds can also drag Soldiers on the ground after they land and before they have time to collapse their parachute canopies, although we had only 6 injuries of this type (0.5% of all injuries). While jumpers are in the air, high winds can push the parachutist away from pre-planned drop zones into obstacles, rougher terrain, or trees. Tree landings are especially hazardous, since a collision with a tree can be followed by an uncontrolled ground impact if the parachutist falls from the tree. In the present investigation, there were 11 injuries (1%) associated with tree landings but because there is no routine collection on the overall number of tree landings we cannot calculate the risk of injury from this event.

8.4.3 Combat Loads and Night Jumps

A number of studies have shown that combat loads increase injury risk[1, 31-33, 35] and this was an independent injury risk factor in the present investigation. Extra equipment increases descent velocity resulting in greater impact energy on ground contact. Since the extra equipment is lowered on a strap before ground impact and arrives on the ground before the jumper, the equipment may also create a landing zone hazard. It has also been hypothesized that combat loads may increase the risk of entanglements.[49] However, in the present investigation, there was little difference in entanglement incidence between administrative/non-tactical jumps (0.30/1,000 jumps) and combat loaded jumps (0.24/1,000 jumps), respectively (RR(admin/combat)=0.80, 95%CI=0.41-1.57, p=0.52).

Another classic airborne injury risk factor is a night jump[1, 28, 31-35] and this was an independent injury risk factor in the present study. During night jumps, Soldiers have reduced ability to see the ground, to perceive distance and depth, and to appreciate the direction of horizontal drift. These and other factors possibly contribute to less controlled landings and reduced ability to see obstacles on the drop zone resulting in higher injury rates.

8.4.4 Humidity, Temperature, and Heat Index

Humidity alone had a minimal and inconsistent influence on injury incidence and was not an independent injury risk factor. On the other hand, both higher temperature and a higher heat index demonstrated a dose-response relationship with injury in the univariate analysis such that as both measures increased so did injury incidence. The heat index involves a complex calculation that attempts to measure the combined effects of heat and humidity and provide some indication of the subjective experience of “heat stress”. In the multivariate analysis, temperature alone was retained in the final model while the heat index was not. This was not surprising since the heat index included temperature in the calculation and was strongly influenced by it.

The association between higher temperature and injury risk are generally in consonance with our previous investigations using some of the same data as in the present study.[1, 31] Pirson and Verbiest[35] also found no association between injuries and humidity but injury rates were higher at temperatures ≥77 degrees Fahrenheit. Assuming a standard pressure of 1013.25 millibars and dry air (gas constant=297 J/kg*K), the density of air would decrease about 11% as the temperature increased from 40 to 95 degrees Fahrenheit (from 1.272 to 1.146 kg/m^3). The less dense air may result in faster descent velocities and this could influence injury rates. The dose-response in the present study found in both the univariate and multivariate analysis was not noted in previous investigations.[1, 31, 35]

8.4.5 Aircraft and Exit Doors

The present study found that the C-17 and C-130 aircraft were associated with higher injury incidences than the other aircraft examined in both the univariate and multivariate analyses. There are several possible explanations for this. First, 38% of jumps from C-130 and C-17 aircraft were night jumps, whereas only 2% of jump from C-23, C-160, CH-47, UH-60 and C-212 were night jumps. Night jumps had a higher injury rate in the present investigation and in other studies.[1, 31-33, 35] However, night jumps would have been a covariate in the multivariate analysis so this factor alone would not likely account for the differences in injury incidence between aircrafts. Other factors may include jump altitude and exit doors. Most (82%) of jumps from the C-17 and C-130 aircraft were conducted at 800 feet above ground level (AGL), while most (92%) jumps from C23, CH47, UH60, and C212 aircraft were conducted at 1250 feet AGL or higher. Higher jump altitudes may have allowed jumpers to achieve better canopy control and provide more time to prepare for landing. In addition, CH47, C23, and C212 jumps were conducted off the tailgate of the aircraft and not out of side doors like the C130 and C17. In tailgate exits, jumpers hooked their static lines to starboard-side anchor cables utilizing a reverse or upside-down bite on the static-line with their left hand. This could have reduced potential static line injuries because it was less likely that a jumper's hand or arm could be routed around the static-line. The distance between where the jumper released grip on the static line and the point where his feet left the aircraft increased significantly with tailgate exits. Finally, in rotary wing aircraft (CH-47, UH-60) jumpers have more space during exits and during descents, less probability of entanglements, and can better concentrate on landing procedures. Thus, some combination of higher jump altitudes, less probability of static line problems, and better jumper spacing during descents may explain the lower injury rates in the C-23, CH-47, UH-60, and C-212 aircrafts.

Previous studies[1, 31, 32] have compared jump injury rates between fixed wing and rotary aircraft and found that fixed wing aircraft had higher injury risk. Almost all (94%) of jumps from rotary wing aircraft in the present investigation were administrative/non-tactical daytime jumps. If only T-10D administrative/non-tactical, daytime jumps were considered, injury rates in the present investigation were 5.9/1,000 jumps with the fixed wing aircraft and 1.2/1,000 jumps for the rotary wing aircraft (RR (fixed/rotary)=4.81, 95%CI=1.79-12.88, $p<0.01$). There were only 445 administrative/non-tactical, daytime, T-11 jumps from rotary aircraft and no injuries occurred; with the fixed wing aircraft (n=14,562) the injury incidence was 4.3/1,000 jumps under these conditions.

8.4.6 Military Rank

Officers were at lower injury risk than enlisted soldiers. Officers were generally the first to exit aircraft and were not involved in shuffling to the door and the general rush to exit the aircraft before it passed beyond the drop zone. They were thus more likely to make a correct and stronger exit and had more air space and a better view of the drop zone to prepare for landing. On combat loaded jumps, officers generally exited aircrafts with a lighter load than other service members since they carry lighter weapons and equipment. This may have reduced ground impact forces. Educational attainment may also be a factor. Most enlisted members are high school graduates (or the equivalent) while most officers are college graduates or higher. [58] There appears to be a graded relationship between injury-related morbidity/mortality and educational attainment and/or various measures of intelligence in both military[59, 60] and civilian[61, 62] studies. Greater educational attainment may be associated with behaviors conducive to injury prevention[63] and/or the ability to more effectively process information relating to risk reduction. Other as-yet unidentified factors may also play a role in this apparent difference in injury risk.

8.4.7 Drop Zone

The major drop zones at Fort Bragg are very similar but do have some minor differences. Sicily and Holland drop zones have a mixture of sandy and hard-packed soil with sparse grass and other low lying vegetation. There is a hard packed dirt airstrip down the middle of both, and both are surrounded by dense pine forests. Additionally, Holland is located on top of a ridgeline with sloping sides and an Airfield Seizure Training Facility adjacent to the Flight Landing Strip (FLS). Normandy and Salerno have similar terrain with the exception of no FLS. Nijmegen drop zone is much shorter and narrower than the others, with prominently hilly terrain on the northern side. Nijmegen does have a dilapidated and overgrown FLS which is no longer serviceable. Luzon drop zone is located on Camp Mackall, which is on the western side of the Fort Bragg reservation. It also has a FLS and its trailing edge borders a heavily traveled state highway. St Mere Eglise has light foliage and a noticeably wide and steep ravine on the middle east side of the drop zone. Gela and Contentin are Sicily and Normandy drop zones, respectively, approached by aircraft from the opposite (South to North) side. These drop zones have all undergone terrain changes in the last twenty years due to construction to control erosion.

Previous literature indicated that airborne drops onto sandy drop zones were less hazardous than jumps onto rougher terrain,[34] or onto dirt landing strips with uneven and unimproved areas around the landing area.[28] Ninety-eight percent of jumps covered by this report occurred onto drop zones at Fort Bragg (Sicily, Luzon, Normandy, Holland, Nijmegen, Salerno, Saint Mere Eglise, Gela, and Contentin). Overall, there were some differences in injury incidence among these areas in the univariate analysis, although drop zone was not an independent injury risk factor in the multivariate model. Luzon had a lower injury incidence than Sicily in the univariate analysis but drop zone was not included in the multivariate analysis. This appeared to be primarily because 69% of jumps on Luzon were administrative/nontactical daytime jumps whereas on Sicily only 46% of jumps were of this type. As noted above, administrative/nontactical daytime jumps have lower injury rates than nighttime or combat loaded jumps.[1, 25, 28, 31-34] St Mere Eglise and Gela also had lower injury rates than Sicily, and Contentin a higher rate, but the number of jumps onto these drop zones were very small.

Less than 2% percent of jumps examined in this investigation occurred at drop zones off Fort Bragg including Clute, Rock, and Geronimo. Jumps at Clute drop zone were performed as part of the 64th Annual Convention of the 82nd Airborne Division in Charleston, West Virginia. Jumps at Rock drop zone were conducted as part of the Little Rock Air Force Base Air Show near Little Rock, Arkansas. Jumps at Geronimo drop zone were part of an airborne insertion into the Joint Readiness Training Center (JRTC) at Fort Polk, Louisiana. The single operation at Geronimo involved a night jump with combat loads from C130 (92% of jumps) and C17 (8% of jumps) aircraft. This was the first time an Airborne brigade combat team had conducted an operation of this size into the JRTC and the unfamiliarity with the drop zone paired with the nighttime combat loaded operation may have contributed to the high casualty rate. Because of the lack of operational and weather data on the Geronimo drop zone the multivariate procedure excluded this jump.

9 CONCLUSIONS AND RECOMMENDATIONS

Compared to the T-10, the T-11 parachute had a lower injury incidence under virtually all operational conditions examined here, except in the very rare case of an entanglement. The T-11 had lower injury risk even after controlling for other major and significant injury risk factors including night jumps, combat loads, higher wind speeds, higher temperatures, and type of aircraft. Injury risk was lower in almost all strata of these independent risk factors. A major reason to use the T-11 during military mass tactical operations is the lower injury rate under virtually all operational conditions examined.

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Appendix A

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